Edward H. Bair[1], Karl Rittger[2], S. McKenzie Skiles[3], and Jeff Dozier[4] (in press), An examination of snow albedo estimates from MODIS and their impact on snow water equivalent reconstruction, Water Resources Research.

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## Key Points

- An updated broadband snow albedo model & statistical fit are presented for the western U.S. mountains
- Remotely sensed snow albedo from MODIS shows 4-6% RMSE with no bias validated by measurements over 1600 days at 3 high-altitude sites
- Reconstructed SWE with 5-11% RMSE and 0-3% bias is achieved using remotely sensed albedo

## Abstract

Snow albedo is a dominant control on snowmelt in many parts of the world. An empirical albedo decay equation, developed over 60 years ago, is still used in snowmelt models. Several empirical snow albedo models developed since show wide spread in results. Remotely sensed snow albedos have been used in a few studies, but validations are scarce because of the difficulty in making accurate in situ measurements. Reconstruction of snow water equivalent (SWE), where the snowpack is built in reverse, is especially sensitive to albedo. We present two new contributions: (1) an updated albedo model where grain size and light absorbing particle (LAP) content are solved for simultaneously; (2) multiyear comparisons of remotely sensed and in situ albedo measurements from three high-altitude sites in the western U.S. Our remotely sensed albedos show 4 to 6% RMSE and negligible bias. In comparison, empirical albedo decay models, which require extensive in situ measurements, show RMSE values of 7 to 17% with biases of -6 to -14%. We examine the sensitivity of SWE reconstructions to albedo error at two sites. With no simulated error in albedo, reconstructed SWE had MAE values of 7 to 13% and 5-6% bias. The accuracy actually improved with some simulated added error, likely because of a fundamental bias in the reconstruction approach. Conversely, the best age-based decay model showed an 18-20% MAE and bias in reconstructed SWE. We conclude that remotely sensed albedos where available are superior to age-based approaches in all aspects except simplicity.

*Figure 1. Broadband snow albedo α vs. effective optical grain radius r for five combinations of models and parameters. Curves shown are for clean snow and clear sky conditions with an air mass of 1.5. Additional information about the model runs is given in Table 1.*

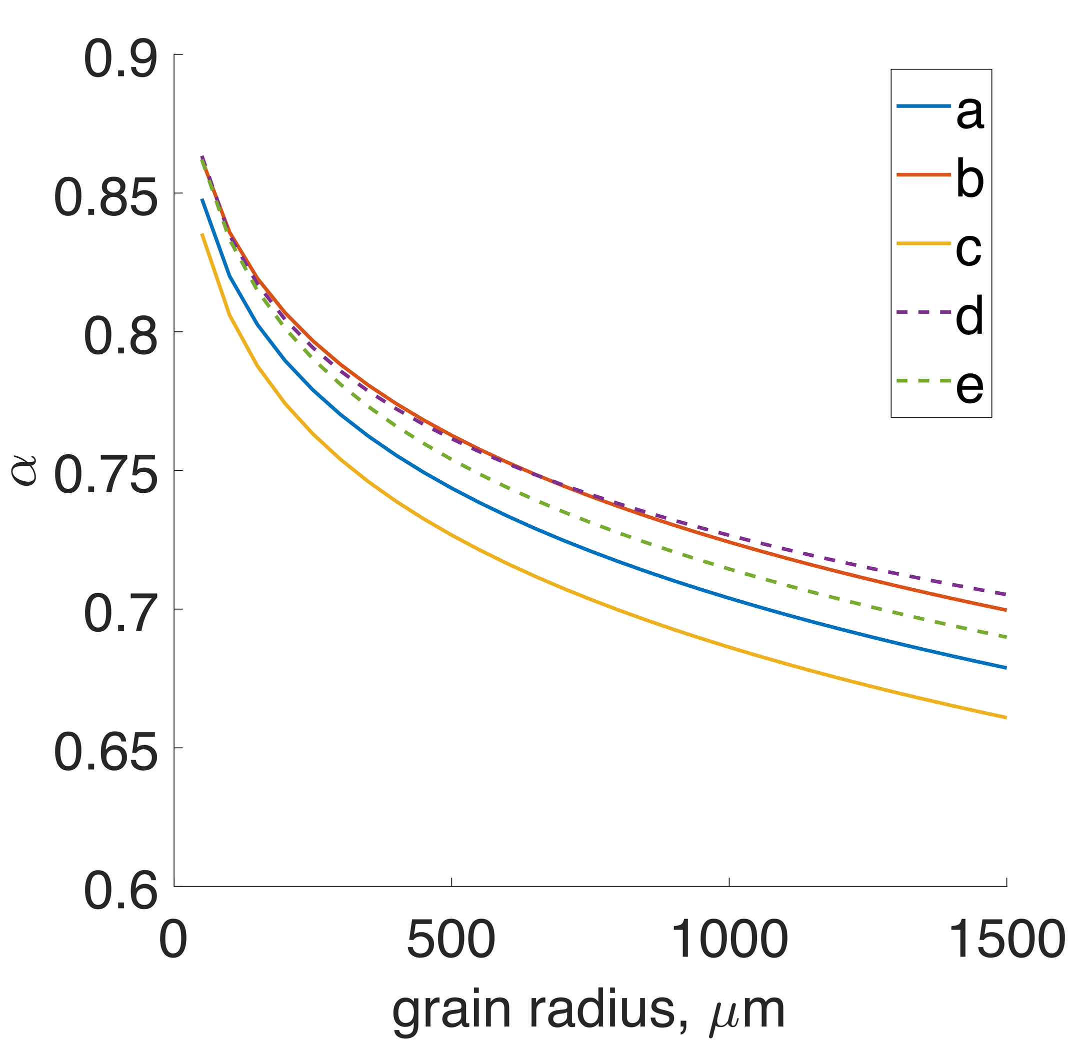
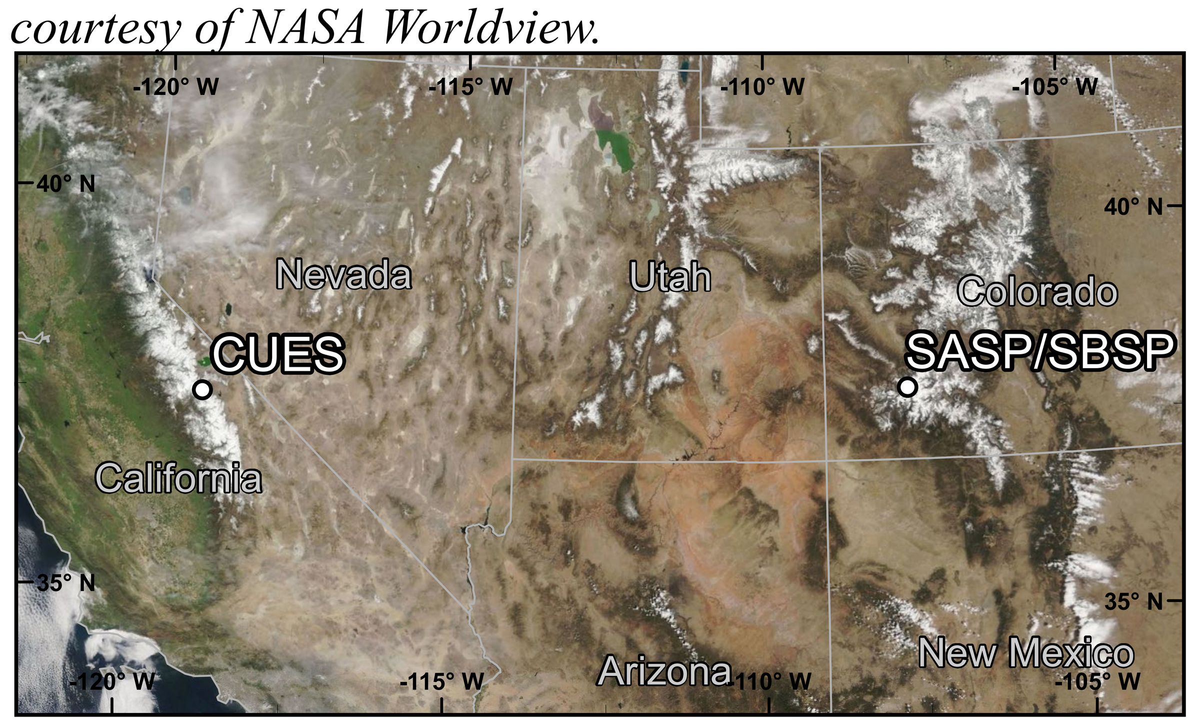



*Table 1 Snow reflectance model, atmospheric model, atmospheric profile, and surface altitude for the five broadband albedo curves shown in Figure 1. For the atmospheric model: SBDART is the Santa Barbara DISORT Atmospheric Radiative Transfer model (Ricchiazzi et al., 1998), and SMARTS is the Simple Model for Atmospheric Radiative Transfer (Gueymard, 2001, 2005).*

| Label in Figure 1 | Snow reflectance model | Atmospheric model | Atmospheric profile | Surface altitude, km |
|---|---|---|---|---|
| a | Wiscombe & Warren, 1980 | SBDART | Mid-Latitude Winter | 3 |
| b | Wiscombe & Warren, 1980 | SBDART | Subarctic Summer | 0 |
| c | Wiscombe & Warren, 1980 | SMARTS | Mid-Latitude Winter | 3 |
| d | Gardner & Sharp, 2010 | SBDART | Subarctic Summer | 0 |
| e | Dang et al., 2015 | SBDART | Subarctic Summer | 0 |

*Figure 2 Map of CUES and SASP/SBSP. MODIS imagery courtesy of NASA Worldview.*



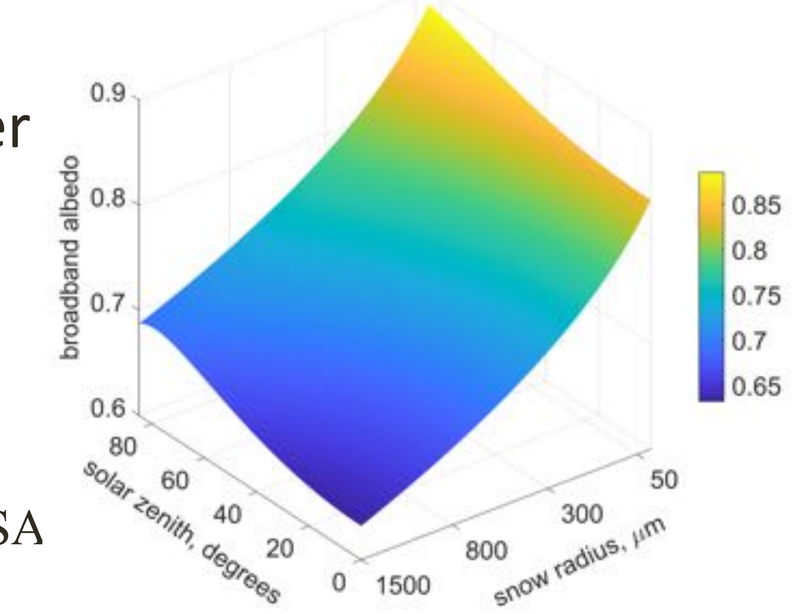




*Figure 3. Broadband albedo of clean snow as a function of grain size (effective optical radius) and solar zenith angle, covering every combination of snow radii from 30 to 1500 μm and solar zenith angles from 0° to 86°.*

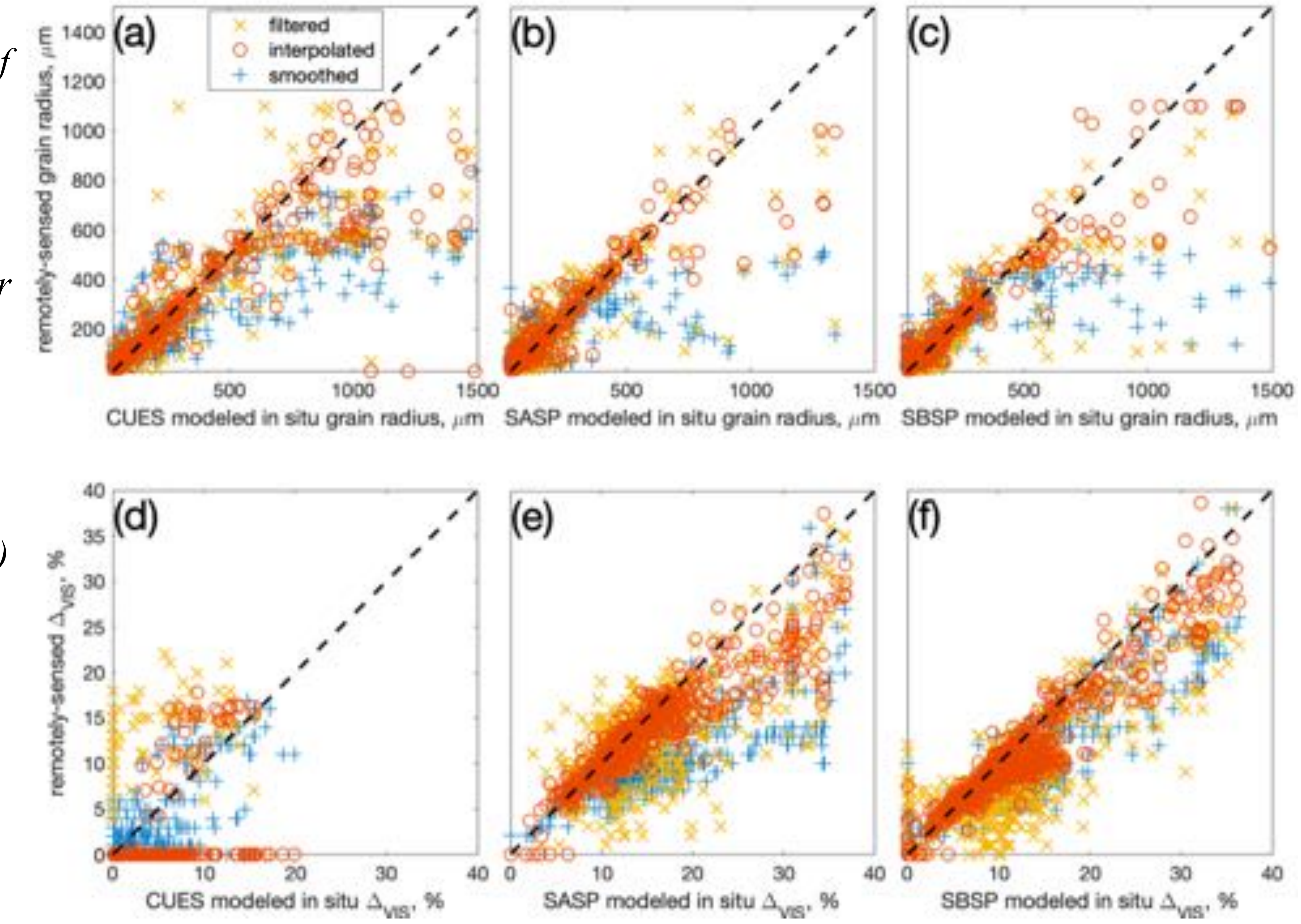



*Figure 4. Remotely-sensed grain radius (top row) vs. modeled value from in situ measurements of albedo and ΔVIS (bottom row) for CUES (a & d); SASP (b & e); and SBSP (c & f). The different colored markers represent the three different levels of filtering, interpolation, and smoothing.*

*Figure 5 Scatter plot of modeled vs. measured albedo at CUES using remotely sensed albedos and those from the BATS aged-based model. N=356 days of albedo measurements are plotted .*

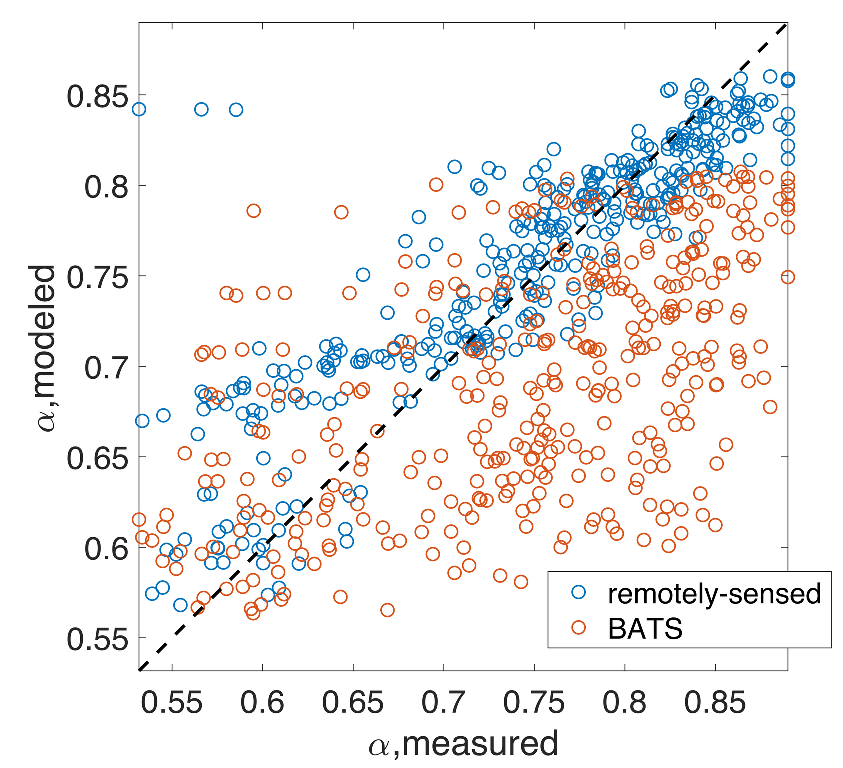
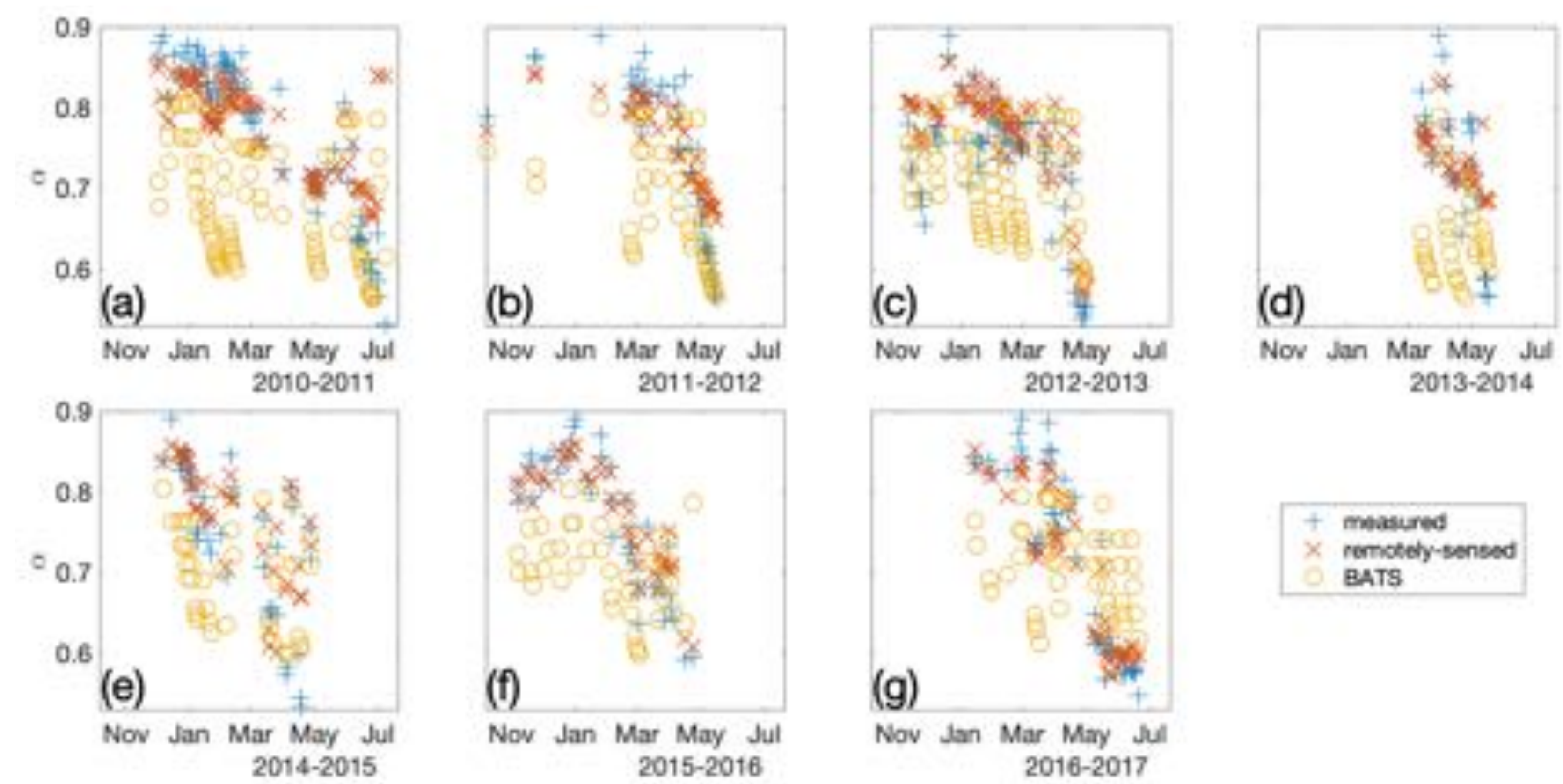



*Figure 6 Time series of albedo at CUES using measured, remotely sensed, and the BATS aged-based albedos from the water years 2011 to 2017 (a-g).*



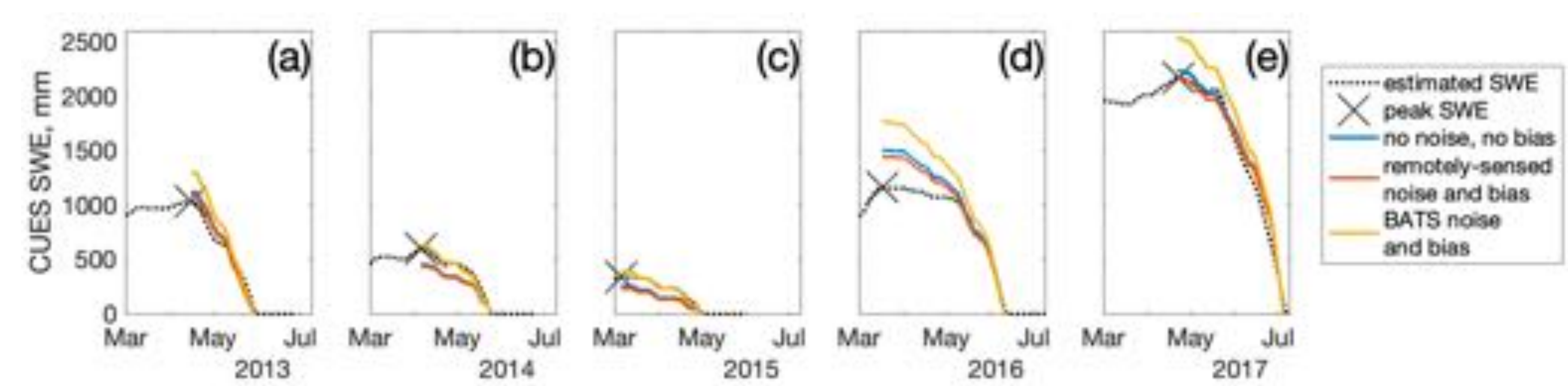




*Figure 7 Reconstructed SWE at CUES for 2013-2017 (a-d) using three different simulated error scenarios for snow albedo: no error; a remotely sensed noise and bias error; and the BATS noise and bias error.*

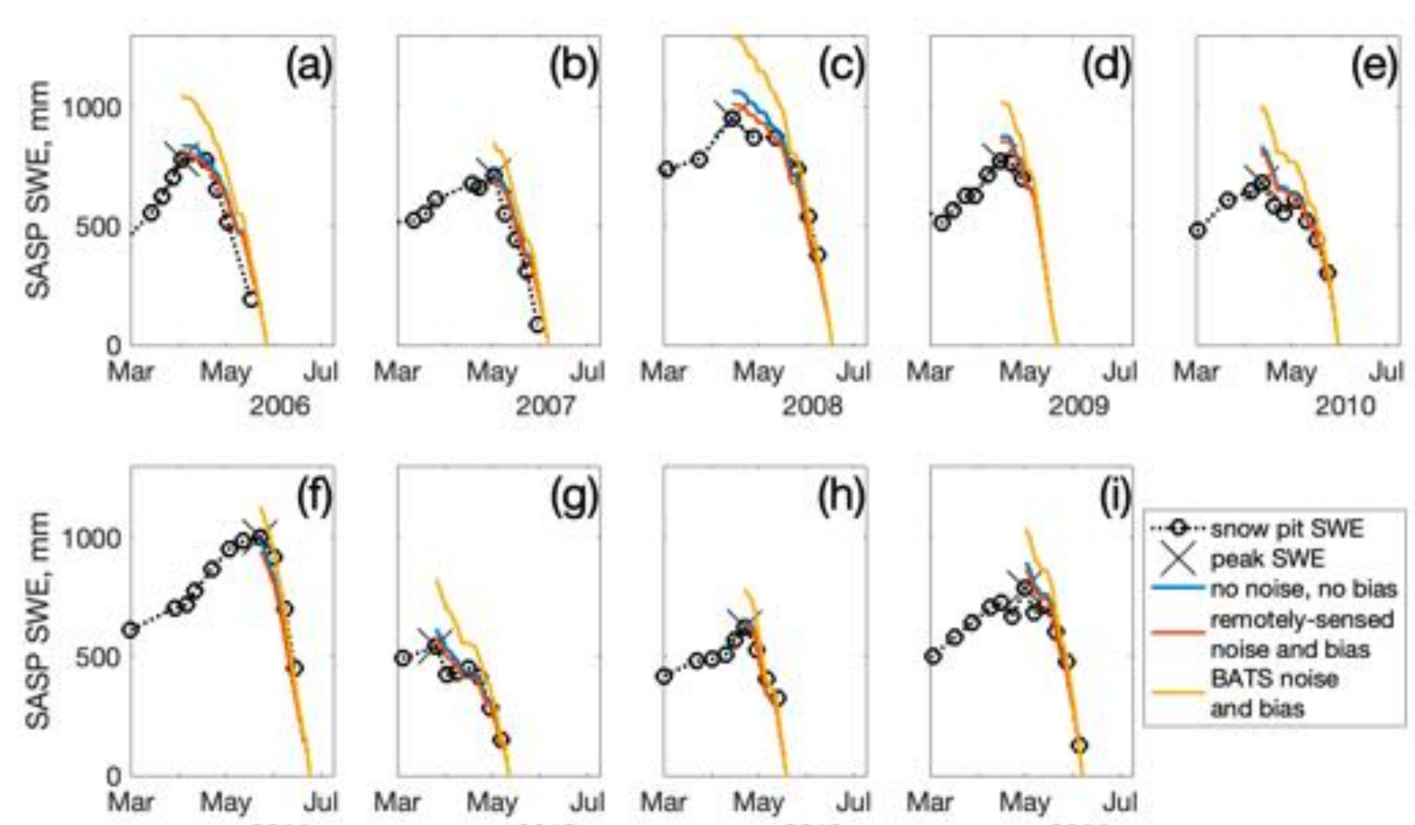



*Figure 8 Reconstructed SWE at SASP for 2006-2014 (a-i) using three different simulated error scenarios for snow albedo: no error; a remotely sensed noise and bias error; and the BATS noise and bias error.*

Acknowledgements

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